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FINAL TECNICAL REPORT (FEB 2012)

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Contract/Grant Title: (HBCU) Light localization and switching with photonic defects and surfaces

Contract/Grant #: AFOSR #FA9550-09-1-0474 (CFDA # 12.800)

Program Manager: Dr. Arje Nachman-NE

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Abstract:

The primary objective of this project is to develop research programs at the frontier of nonlinear optics/photonics that could lead to fundamental understandings in scientific knowledge as well as possible applications of direct interest to AFOSR. Specifically, the proposed studies include (1) optical “fabrication” of photonic lattices with desired defects and surface structures, (2) linear and nonlinear defect modes for light guiding and switching, (3) defect-defect and defect-soliton interactions for light routing and coupling, and (4) Tamm and Shockley-like surface states in photonic interfaces and superlattices. These studies will advance the knowledge in several interdisciplinary areas such as defect and surface phenomena in condensed matter physics, and will also have application potentials.

Our previous work on nonlinear optics/photonics research was supported by a research grant from AFOSR (#FA9550-06-1-0054, Point of contact: Dr. Nachman, AFOSR/NE), which ended in November, 2008. Earlier progress and success has been detailed in the final technical report submitted for that project, and has also been presented at the annual workshops on Nonlinear Optics organized by Dr. Nachman.

Our current 3-year contract (#FA9550-09-1-0474; Point of contact: Dr. Nachman, AFOSR/RSE) started in early 2009. During the past three project years, the PI’s group published nearly 40 referred papers and authored 3 book chapters that credited AFOSR, and about a dozen students at SFSU have participated in the AFOSR funded project. Our work has been featured in *Optics & Photonic News* as one of the major breakthroughs in optics of the year, has been cited frequently in literature, and has been presented in several invited and contributed talks at leading professional meetings and workshops. Here, we provide a summary report for our accomplishments during the past three years.

Summary of Major Efforts and Accomplishments:

In the last three years, we successfully demonstrated several phenomena related to light localization, light beam manipulation, and light signal routing in optically-induced photonic bandgap structures, including linear and nonlinear control of light in uniform optical periodic structures as well as in defects and surfaces of specially-designed photonic lattices. In particular, we demonstrated photonic bandgap guidance in lattices with structured defects, and linear and nonlinear optical surface states at the interfaces between homogeneous media and photonic lattices. We are happy to report that we have made significant progress in this funded project with more than 30 scientific research papers published in top-rated refereed journals including *Optics Letters* and *Optics Express*. (See attached list of publications that acknowledged the support from AFOSR). In addition, several students have actively involved in this project, and close collaboration has been maintained with other principal investigators supported by AFOSR. Below, we provide a brief summary of our major accomplishments.

1. *Linear and nonlinear control of self-accelerating Airy beams and applications*

We demonstrated the projectile motion of two-dimensional truncated Airy beams in a general ballistic trajectory with controllable range and height. We show that the peak beam intensity can be delivered to any desired location along the trajectory as well as repositioned to a given target after displacement due to propagation through disordered or turbulent media. We also demonstrated persistence and break-down of Airy beams driven by an initial nonlinearity. These studies may provide insights to laser filamentations in atmospheric environment. This part of the work has merited two papers published in *Optics Letters*.

2. *Image transmission using linear and nonlinear photonic lattices*

We proposed and demonstrated two different schemes for image transmission through photonic structures. The first one is linear transmission based on coherent destruction of tunneling (CDT), and the second one is nonlinear transmission based on gap soliton formation. Both schemes and demonstrations were published in two papers in *Optics Letters*.

3. *Bandgap guidance of optical vortices by photonic defects*

We experimentally demonstrate linear bandgap guidance of optical vortices as high-gap defect modes (DMs) in two-dimensional induced photonic lattices. We show that donut-shaped vortex beams can be guided in a tunable negative (lower-index) defect, provided that the defect strength is set at an appropriate level. Such vortex DMs have fine features in the “tails” associated with the lattice anisotropy and can be considered as a superposition of dipole DMs. This work has been published in *Optics Letters*.

4. *Nonlinear beam deflection in photonic lattices with negative defects*

In collaboration with AFOSR contractor Dr. J. Yang, we demonstrated both theoretically and experimentally that a nonlinear beam can be reflected by a negative defect in a photonic lattice if the incident angle is below a threshold value. Above this threshold angle, the beam simply passes through the defect. This phenomenon occurs in both one- and two-dimensional photonic lattices,

and it provides a way to use the incident angle to control beam propagation in a lattice network. These results could be useful for developing devices based on beam deflection and switching. The work has been published in *Physics Review A*.

5. Optical trapping and manipulation by specially engineered beams

In addition, in collaboration with AFOSR/MURI contractor Prof. D.N. Christodoulides and other co-workers, we demonstrated trapping and guiding micro-particles and aerosols with morphing auto-focusing Airy beams and specially designed optical bottle beams. This part of work has been published in *quite a few Optics Letter papers*.

6. Molding the Flow of Surface Plasmon Polaritons in Real-time

Molding the flow of Surface Plasmon Polaritons (SPPs) at a subwavelength scale paves the way for ultra-compact integrated optical circuits. Traditional plasmonic elements based on either structuring metal surfaces or placing discrete dielectric structures on metal surfaces suffer from considerable scattering losses due to the abrupt discontinuities in the material properties or geometries and rely on fabricated permanent structures which are difficult to reconfigure. To circumvent these problems, we have recently demonstrated a novel approach of plasmonic Airy beams (PABs) based on nondiffracting wave-packets for dynamically routing SPPs in real-time. This part of work has been published in *Optics Letters*, and has been reported in several science news media.

Interactions/Collaborations:

Participation of students and postdoc researchers in the proposed research

The P.I. has actively engaged students, especially underrepresented minorities, in his research. Currently, there are eight undergraduate and M.S. graduate students including woman and minority students working in PI's lab, with support from AFOSR and NSF.

Collaboration with other scientists

During the last couple of years, the P.I. has been in closed contact/collaboration with theorists and applied mathematicians including Prof. D.N. Christodoulides at CREOL, University of Central Florida, Prof. J. Yang at University of Vermont, and Prof. N. K. Efremidis at University of Crete, Greece. Some of them are currently also AFOSR contractors in the nonlinear optics program. The P.I. will continue the collaboration with other contractors and discuss with them about productive plans and future collaboration for the AFOSR projects.

Publications Acknowledged AFOSR Support during 2009-2012:

Book in Press:

Nonlinear Photonics and Novel Phenomena, [Springer Series in Optical Sciences](#), Z. Chen and R. Morandotti eds., to be published by Springer (2012).

Book Chapters:

J. Yang, X. Wang, J. Wang, and Z. Chen, “Light localization by defects in optically induced photonic structures”, Invited Book Chapter, in *Nonlinearities in Periodic Structures and Metamaterials*, [Springer Series in Optical Sciences](#), Vol. 150, C. Denz, S. Flach, and Y. Kivshar eds., p. 127-143 (Springer, 2010). ISBN: 978-3-642-02065-0

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P. Zhang, Cibo Lou, Yi Hu, Sheng Liu, Jianlin Zhao, Jingjun Xu, and Zhigang Chen, “Spatial beam dynamics mediated by hybrid nonlinearity”, in *Nonlinear Photonics and Novel Phenomena*, [Springer Series in Optical Sciences](#), . Z. Chen, and R. Morandotti eds. to be published (2012).

Referred Journal Articles:

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3. P. Zhang, R. Egger*, and Z. Chen, “Optical induction of three-dimensional photonic lattices and enhancement of discrete diffraction”, *Optics Express*, **17**, 13151 (2009).
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Selected and published by [Virtual Journal of Atomic Quantum Fluids](#), (January, 2010).
10. X. Gan, P. Zhang, S. Liu, Y. Zheng, J. Zhao, and Z. Chen, “Stabilization and breakup of optical vortices in presence of hybrid nonlinearity”, *Optics Express* **17**, 23130 (2009).

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12. P. Zhang, C. Lou, S. Liu, J. Zhao, J. Xu and Z. Chen "Tuning of Bloch modes, diffraction and refraction by two-dimensional lattice reconfiguration", *Optics Letters*. **35**, 892 (2010).
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